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Potential temperature as a dependent variable in the Met.O.20 11-level model.

by

T. Davies.

Meteorological Office (Met.O.11)
London Road,
Bracknell, Berkshire
United Kingdom.

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1. INTRODUCTION

From forecasts produced by Met.O.11 and Met.O.2b, it is known that significant synoptic differences between the 11-level model (Saker, 1975) and the operational 10-level model can occur by the third day of a forecast. In a series of experiments to find out why there are differences between the models it was decided to run a version of the 11 level model using potential temperature θ as a dependent variable instead of temperature T. This change mades the 11-level model equations comparable with those of the σ-coordinate version of the 10-level model (Temperton, 1976).

2. THE EQUATIONS

The original energy equation (ignoring terms on the R.H.S.)

$$\frac{\partial}{\partial t}(p_* T) + \frac{1}{a\cos\phi}\left[\frac{\partial}{\partial\lambda}(uT) + \frac{\partial}{\partial\phi}(vT\cos\phi)\right] + \frac{\partial}{\partial\sigma}(p_*\dot{\sigma}T) - \frac{\kappa T\omega}{\sigma} = 0$$

becomes

$$\frac{\partial}{\partial t}(p_*\theta) + \frac{1}{a\cos\phi}\left[\frac{\partial}{\partial\lambda}(u\theta) + \frac{\partial}{\partial\phi}(v\theta\cos\phi)\right] + \frac{\partial}{\partial\sigma}(p_*\dot{\sigma}\theta) = 0\,,$$

where $u = p_* u$ and $v = p_* v$, otherwise notation is standard.

The only change in terms on the R.H.S. involves the diffusion terms defined by

$$D_T = K_T\left(\frac{1}{p_*^2}\left|\nabla\cdot p_*^{\kappa+1}\nabla\left(\frac{T}{p_*^{\kappa}}\right)\right|\right)\nabla\cdot p_*^{\kappa+1}\nabla\left(\frac{T}{p_*^{\kappa}}\right)$$

which simplifies to

$$D_\theta = K_\theta\left(\frac{1}{p_*}\left|\nabla\cdot p_*\nabla\theta\right|\right)\nabla\cdot p_*\nabla\theta\,.$$

In the equations of motion, the part of the pressure gradient terms of the form $RT\frac{\partial}{\partial x}(\log p_*)$ was left unaltered. The equations then take the same form as the σ-coordinate version of the operational 10-level model.

However, in terms of potential temperature

$$RT\frac{\partial(\log p_*)}{\partial x} = c_p\left(\frac{\sigma}{1000}\right)^{\kappa}\theta\frac{\partial p_*^{\kappa}}{\partial x}$$

which provides scope for reformulating the pressure gradient term. This is described in section 4.

Changes in the coding of the 11 level model were kept as straightforward as possible. The change from temperature T to potential temperature θ was made on entry to the dynamical equations subroutine and the reverse change was made on exit. The physics routines were thus left unaltered.

It should be noted that since the equation for potential temperature takes a simplified form, coding of the equations alone is more efficient. For example, the adiabatic term $\frac{\kappa T\omega}{\sigma}$ is omitted and the diffusion term takes a more simplified form. $p_*^{\kappa+1}$ is not needed and we need one of either $\log p_*$ or p_*^{κ}. Furthermore, for vertical differencing, θ does not have to be weighted as does the temperature (Rowntree, 1971). It seems reasonable to assume that within a layer θ is constant and thus the weights are all equal to one half.

Three case studies were selected based on data from (i) 14/8/77 (ii) 20/2/77 and (iii) 8/5/77. These cases were chosen since significant synoptic differences were evident by day 3 of the forecasts. Cases (i) and (ii) were run for three days and case (iii) for five days.

3. RESULTS AND CONCLUSIONS

The differences between the θ and T versions of the 11-level model were small by day 3 in all three cases. Comparisons of the performance of the 11-level and 10-level operational models for cases (i) and (ii) have been given by Cullen (1977). Charts for cases (i) and (ii) are not reproduced here since the two forecasts are similar.

Charts for day 3 (PMSL) and day 5 (PMSL and 500mb) for case (iii) are given in figures 1 to 6. Figures 1 and 2 show PMSL at day 3 for the θ-model and T-model respectively. The differences can be seen to be very small.

Case (iii) was run for a further two days to see if the differences became very much larger. Figures 3 and 4 show 500mb for the θ and T models respectively and figures 5 and 6 the corresponding PMSL charts.

Both models produce much the same forecasts. The main differences are at about 60N 120E where the T-model has a low with a double centre at 500mb. At the surface, the complex low pressure area in that area is handled a little differently by the models with the θ -model's surface low further to the South. However, neither model is really correct in this region.

Hovmoller diagrams were produced for case (iii) and compared with similar diagrams produced by the T-model. Once more, differences were found to be small.

In conclusion, differences between the 11-level model and the σ-coordinate version of the operational model are not explained by the use of potential temperature as a dependent variable in the latter. The experiment has been successful only in showing that a potential temperature version of the 11-level model is a viable alternative.

4. PRESSURE GRADIENT EXPERIMENT

A further experiment was conducted by altering the pressure gradient terms in the equations of motion. In the original 11-level model $RT\frac{\partial}{\partial x}\log p_*$ is represented by $R\overline{T}^{x}\delta_x \log p_*$ otherwise, near steep topography, truncation errors become unacceptable (Corby et al 1972). In the potential temperature version of the model it was found that $\theta\frac{\partial}{\partial x}p_*^{\kappa}$ must be represented by $\overline{\theta}^{x}\delta_x p_*^{\kappa}$ for the same reason. Efforts to find an alternative formulation proved fruitless. For example, using $\theta\,\delta_x \overline{p_*^{\kappa}}^{x}$ resulted in a breakdown of the forecast after about one hour.

The case for 14/8/77 was run for three days with the new pressure gradient terms and it was found that the differences between the two potential temperature versions of the 11-level model were very small. This shows that $\theta\partial p_*^{\kappa}/\partial x$ can be used without penalty in the formulation of the pressure gradient term.

ACKNOWLEDGEMENTS

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ntial Temp Experiment
8/5/77

FIG 1.

EXPERIMENT TIME = D003H00 PMSL
CONTOUR INTERVAL = 4.00 MB

POTENTIAL TEMPERATURE θ

level model 8/5/77

FIG. 2.

EXPERIMENT TIME = 0003H00 PMSL
CONTOUR INTERVAL = 4.00 MB

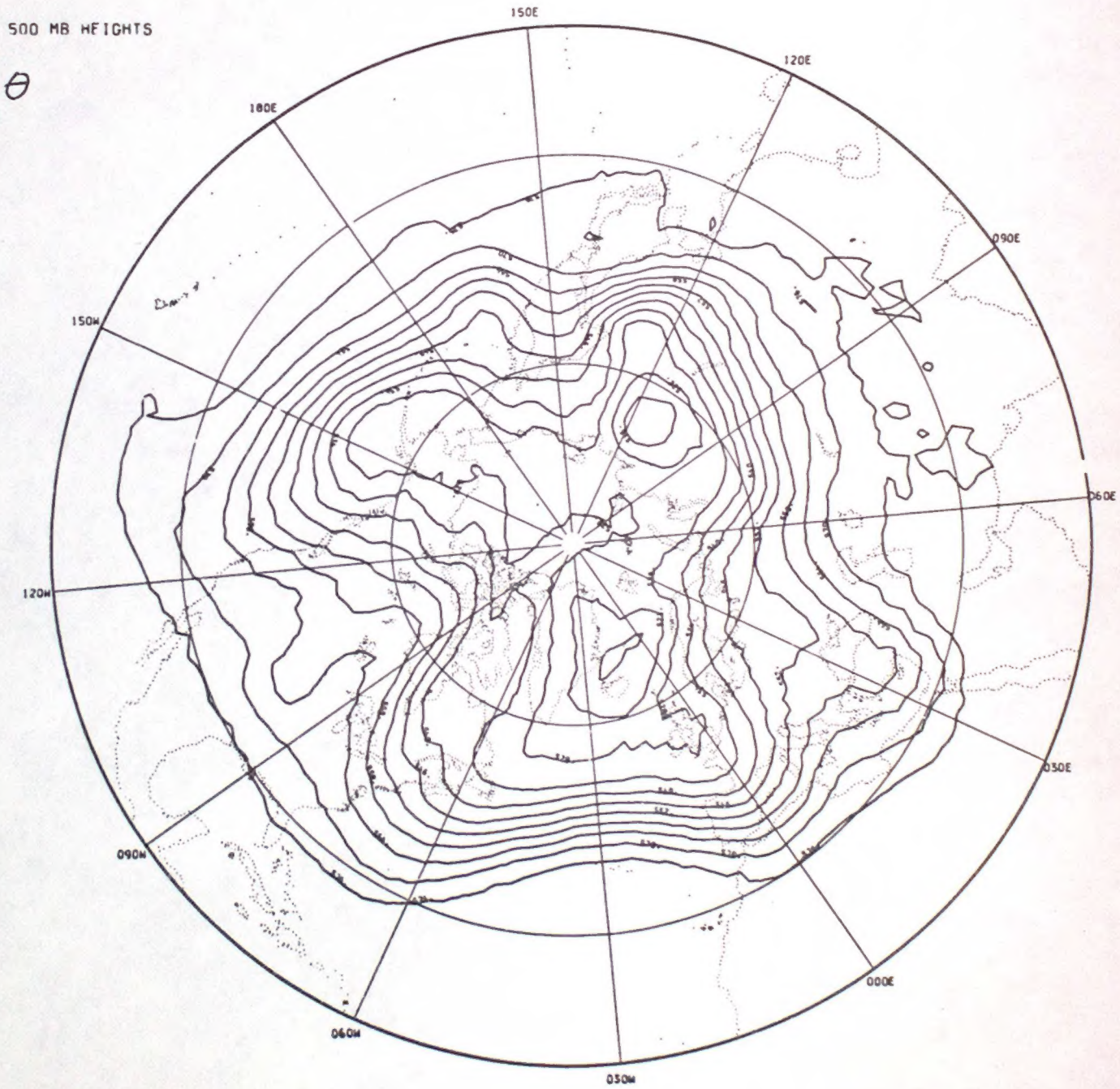
TEMPERATURE T.

Potential Temp Experiment
8/5/77

FIG 3

EXPERIMENT TIME = 0005H00 500 MB HEIGHTS
CONTOUR INTERVAL = 6.00 DEKAMETRES

POTENTIAL TEMPERATURE θ

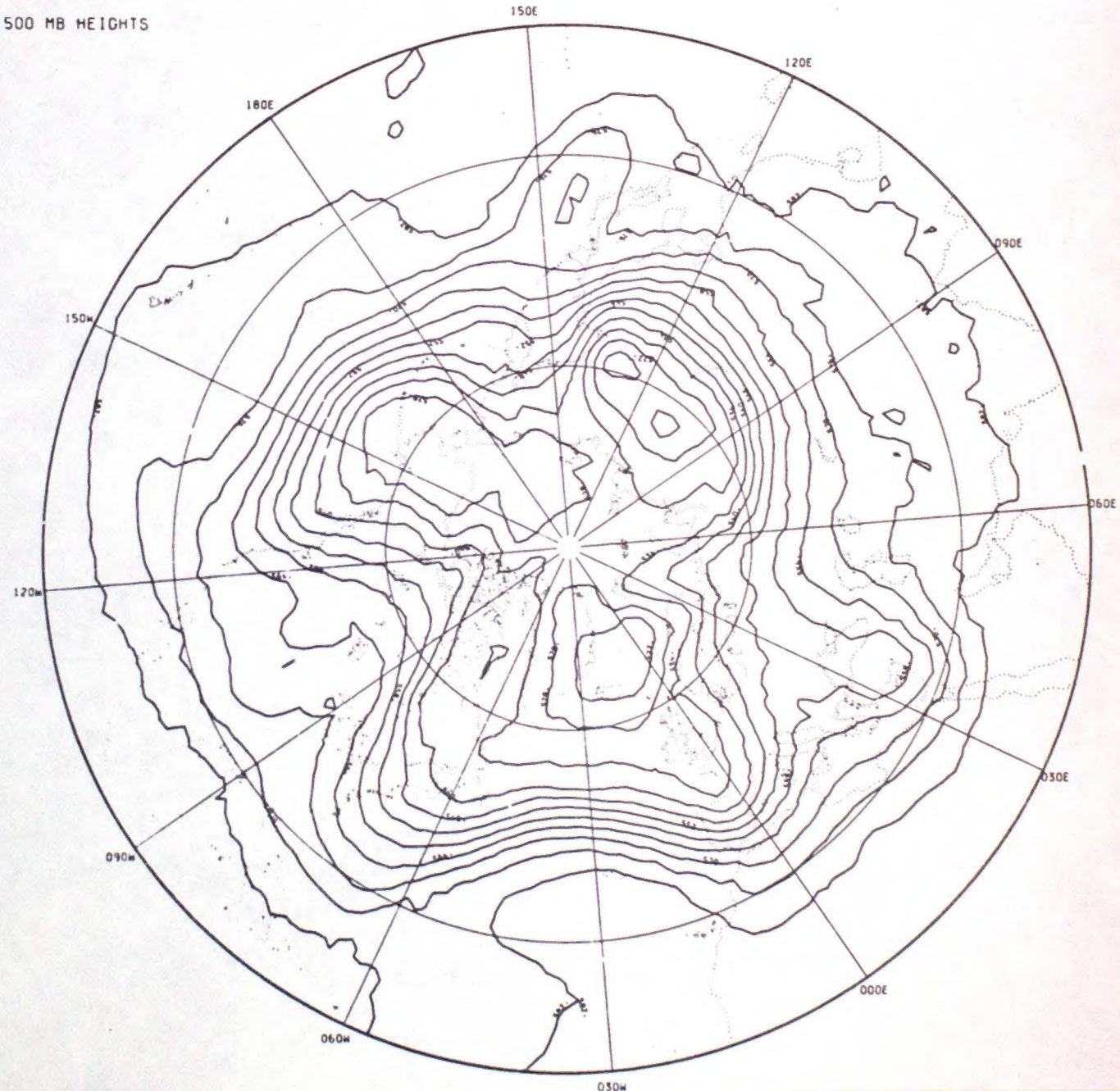


level model 8/5/77

FIG. 4

EXPERIMENT TIME = D005H00 500 MB HEIGHTS
CONTOUR INTERVAL = 6.00 DEKAMETRES

TEMPERATURE T



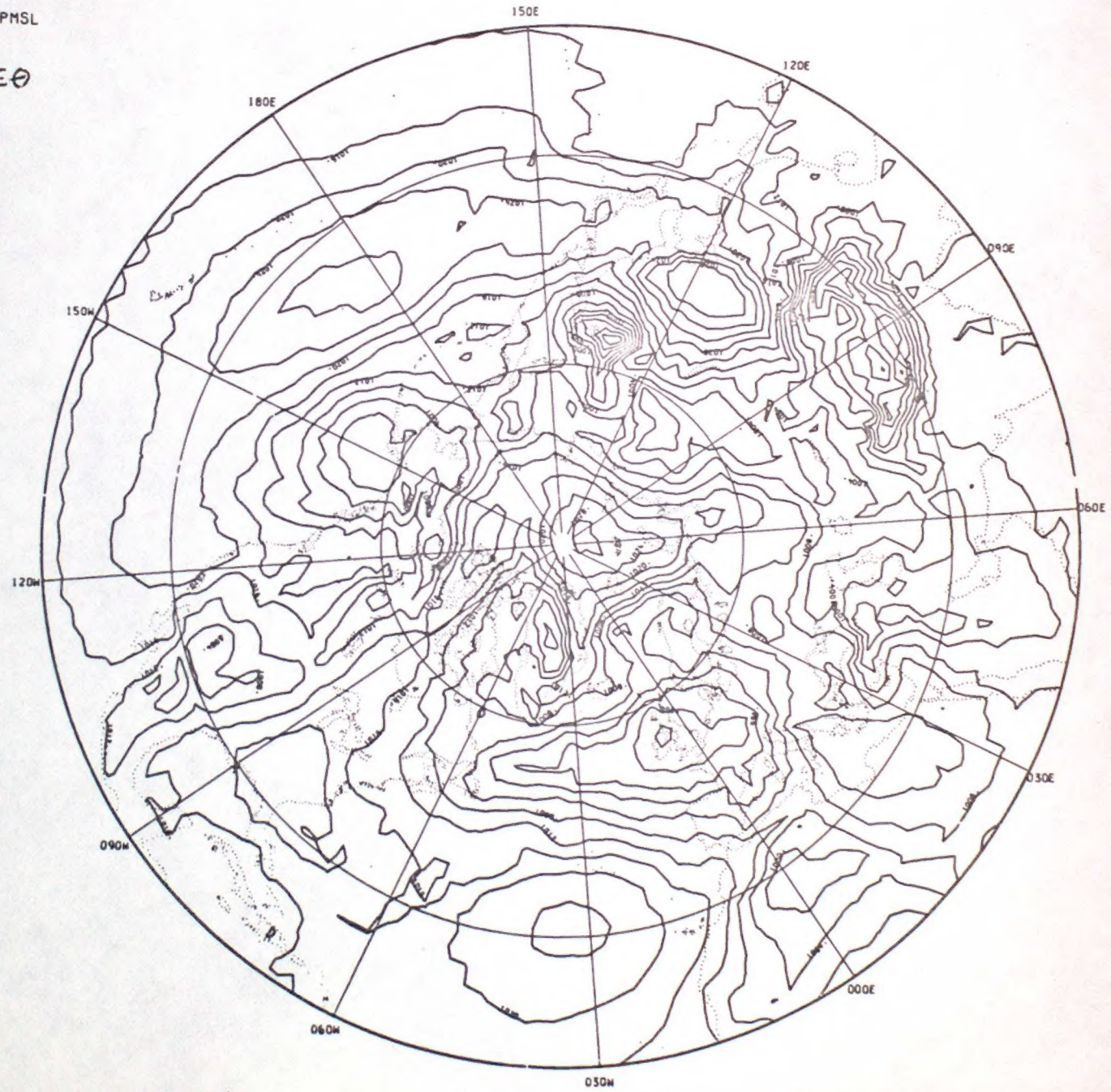
Potential Temp Experiment

8/5/77

FIG 5.

EXPERIMENT TIME = 0005H00 PMSL
CONTOUR INTERVAL = 4.00 MB

POTENTIAL TEMPERATURE θ



Level model 8/5/77

FIG 6.

EXPERIMENT TIME = 0005H00 PMSL
CONTOUR INTERVAL = 4.00 MB
TEMPERATURE T